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TRANSACTIONS.

No. 789.

FLOW OF WATER IN WROUGHT AND CAST-IRON PIPES FROM 28 TO 42 INS. IN DIAMETER.

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Presented at the Annual Convention, 1896.

WITH DISCUSSION.

The water supply of the city of Portland, Ore., is from the Bull Run River, which heads in a lake fed by springs 3 500 ft. above sea level and 10 miles from Mount Hood in the Cascade Mountains. It runs with an average fall of 100 ft. to the mile over a bed of rocks and boulders between high walls of rock and hard pan into the Sandy River, a few miles above the place of its discharge into the Columbia. The water-shed of 220 square miles, now a government reservation, is mountainous, covered with timber, and unfit for settlement or occupation, and the main stream and its tributaries carry down but little sand or gravel, and not enough clay or alluvial soil to color the water during the highest floods. The temperature of the water, which averages about 38° Fahr. in winter, 45° in the spring and fall, and 55° in summer, does not change in passing through 30 miles of pipes.

The minimum discharge is about 70 000 000 galls. in 24 hours, of which a third is now taken for the city water supply.

The water is diverted from the stream at the head of a rapid by means of a canal 400 ft. in length, terminating in a chamber from which it is discharged through a funnel 9 ft. in length and with a diameter tapering from 5 to 3½ ft., the latter being the diameter of the discharge pipe. A 42-in. gate is placed at a distance of 30 ft. from the head for the purpose of regulating or shutting off the water supply to the city. The head lost from the water chamber to a point below the gate is 6 ins. From the head to the foot of the canal there is a fall

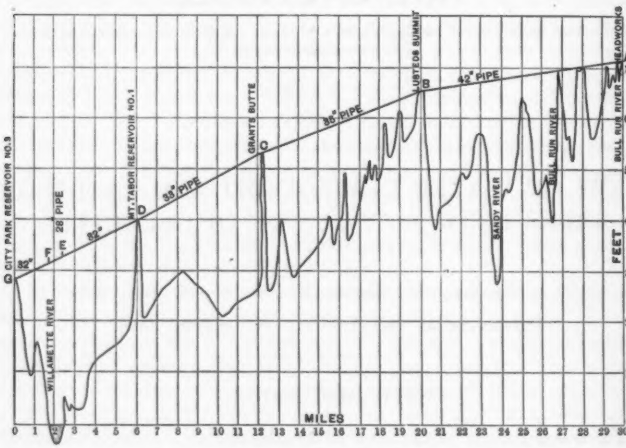

Fig. 1.

in the river of 16 ft. at low water, and as the canal walls are but 3 ft. in height, the flood waters are wasted over the top of the wall and there is but little variation in the level of the water in the water chamber.

The water is conducted to the city through a riveted steel and a cast-iron pipe, the one 24 miles and the other 6 miles in length. The steel pipe extends from the source to a reservoir on the east side of the Willamette River; the cast-iron pipe extends thence to a reservoir on the west side, passing under the river by means of a submerged pipe 2 006 ft. in length, as shown in Fig. 1.

At each reservoir the water ascends vertically into the gate chamber and flows through screens over a weir 6.97 ft. long with two end con-

tractions, which differs from the regulation weir only in having a circular channel of approach. On the outside of the channel there is a a float supporting a gauge, which shows the height H of the water, and the corresponding discharge Q, calculated by the formula,

$$Q = 3.33\ (\text{length} - \frac{H}{5}) \times H^{\frac{3}{2}}$$

This float is adjusted by means of a hook gauge on the outside of the circular channel, but it is found that the height is 0.02 ft. greater on the inside.

The capacity of each reservoir was carefully measured, and the depth of the water in feet and the surface level for each 1 000 000 galls. were marked on a rod attached to the gate house and resting on the bottom.

On March 28th, 1895, 2 995 000 galls. by reservoir measurement was turned into Reservoir No. 1 in 3.7 hours, and 617 000 galls. by weir measurement into other reservoirs, making 3 612 000 galls. in 3.7 hours, or 23 410 000 galls. in 24 hours.

The flow by weir was 23 750 000 galls., or 340 000 galls. more than the reservoir and weir measurements combined. On January 21st, 1896, all of the water was turned out of Reservoir No. 1, and the full flow from Bull Run then turned in, and as the surface of the water rose to each million mark on the rod from 1 to 10, the time was noted and found to be 1 hour and 1 minute in seven instances, and 1 hour and 2 minutes in three, giving a flow of 10 000 000 galls. in 10 hours and 13 minutes, or 23 491 000 galls. in 24 hours. During the whole time the height of water above the weir stood steadily at 1.37 ft. on the outside of the circular approach and 1.39 ft. on the inside, giving a flow in 24 hours of 23 100 000 galls. for the first, and 23 592 000 galls. for the second, which differs only 100 000 galls. from the flow by reservoir measurement.

By tests made carefully at different times, it was ascertained that there was no appreciable leakage, either from the reservoir or from the supply main from Bull Run. As the weir at Reservoir No. 3 on the west side of the river was in all respects similar to that on the east side, it may be assumed that the weir measurements are correct in both cases, taking the heights on the inside of the circular approach.

The steel pipes are composed of 60-in. plates made up in alternate large and small sections, the smaller fitting at each end into the

larger. The plates are double riveted on the straight seams, single riveted on the round, and coated with a preparation of asphalt, which rounds off the projecting edges of the joints and tends to lessen the frictional resistance on the pipes. The rivets were not countersunk.

On the 42-in. pipe, the thickness of the plates corresponds to Nos. 6 and 4, B. W. G., except for about ½ mile on which it is ⅜ in. On the other pipes, 35-in. and 33-in., the thickness is 0.203 in., or No. 6, B. W. G. The diameters are estimated on the inside of the smaller courses, but during the progress of the work it was found that the pressure of the earth filling reduced the vertical and increased the horizontal diameters, the difference being from 1 to 4 ins., according to the depth of the fill and the care exercised in tamping under and around the pipes. To ascertain the effect of this distortion, sections of the pipe were subjected by means of jack screws and loads of earth to external pressures which reduced the vertical diameter within the limits of 1 and 8 ins.; but although without any load there was always a small difference in the transverse diameters, it was found that under any load the mean of the diameters was equal to the diameter of the circular pipe, and that the pipe when relieved from pressure resumed the original form and remained perfectly tight when subjected to a hydraulic pressure of 150 lbs. to the square inch. Assuming the section to be an ellipse the reduction of the area would, under the conditions stated, be inappreciable. Under a heavy water pressure from within, the pipes may have resumed the circular form, but on summits where the water pressure is light, the distortion still remains. The change of section is not apparent to the eye, but it is probable that it exists in all riveted or wrought pipes to an extent depending on the thickness and quality of the plates, the diameters of the pipes, and the depth and character of the filling.

Bends were made by means of joints not more than 6 ins. in width at the widest part, and riveted together in the same manner as the round seams of the pipes, each joint adding a round seam over and above the number required for a straight pipe.

Between the extremities *A* and *D* (Fig. 1) of the steel pipe there are two summits, *B* and *C*, which break the grade and necessitate pipes of different diameters: 42-in. on *A B*, 35-in. on *B C*, and 33-in. on *C D*.

The section *A B* extends from the head works *A* down Bull Run

and across the Sandy River to the summit of the divide between that river and Kelly Creek. As the sides of the Bull Run Canyon are high and in some cases nearly vertical, the pipe line is necessarily thrown on high ground with many summits approaching nearly to the hydraulic grade line. From Sandy River to the summit *B* of the divide between that river and Kelly Creek, the rise is 400 ft. in 4 miles, with grades approaching in places to 45°, as shown on the profile. To avoid slides and vertical cliffs three bridges are necessary, two across Bull Run of 100-ft. and 200-ft. span, and a third of 300-ft. span across Sandy River. The ground is broken and exceptionally rough, requiring many bends, vertical and horizontal. The diameter of this pipe is 42 ins.

The next section extends from *B* along the north slope of the waters of Kelly Creek to the summit *C* of Grant's Butte, over broken and rough ground, requiring many bridges and trestles. The diameter of the pipe is 35 ins.

The next section, *C D*, extends from the top of Grant's Butte to the gate house of a reservoir known as No. 1, with no steep grades except the descent from Grant's Butte and the ascent to the reservoir.

From *D* to a reservoir, *G*, on the west side of the river, there is a 32-in. cast-iron pipe, and a section, *E F*, of 28-in. pipe passing under the river. The ground is comparatively level, but a considerable curvature is necessary in order to keep the pipe line within the limits of roads and streets.

The bends in the several pipes are as follows:

	Diameters of Pipes. Inches.				
	28	32	33	35	42
Total number of bends	2	17	85	141	225
Total degrees of curvature	21°	800°	404°	782°	1 913°
Average per mile	6°	14°	62°	101°	191°
Extra joints per mile for bends	....	....	11	29	42
Maximum radius	11'	11'	38'	38'	38'
Minimum radius	11'	11'	14'	38'	14'

The lengths of the pipes were calculated from the number of joints and checked by actual measurement. The elevations are measured by spirit level several times during the progress of the work and verified by a survey made recently.

For convenience of reference and calculation, the equations deduced

from the hydraulic formula, $v = c\sqrt{r\,s}$, will be placed under the following forms:

v = velocity in feet per second.

d = diameter of the pipe in inches.

q = discharge in 1 000 000 galls. per day.

n = degree of roughness in the Kutter formula.

c = coefficient of discharge corresponding to n.

h = hydraulic grade, or loss of head per 1 000 ft. of pipe on the hydraulic grade line.

p = piezometer grade or loss of head per 1 000 ft. estimated on the piezometer grade line or lines; p cannot be greater than h, but may have any smaller value according to the discharge.

$$v = \frac{c\sqrt{d\,p}}{219.19} \quad \text{.......... (1)}$$

$$q = \frac{c\sqrt{d^5\,p}}{62\,151} \quad \text{.......... (2)}$$

$$c = q \times \frac{62\,151}{\sqrt{d^5\,p}} \quad \text{.......... (3)}$$

$$p^{\frac{1}{2}} = q \times \frac{62\,151}{c\sqrt{d^5}} \quad \text{.......... (4)}$$

$$o = l \times p \quad \text{.......... (5)}$$

Equation (5) gives the loss of head in a length, l, of pipe.

To determine the discharge, q, through a series of compound pipes.

$$q = \sqrt{\frac{H}{o}} \quad \text{.......... (6)}$$

In this equation H is the vertical distance or available head from the upper to the lower end of the compound pipe, and o is the sum of the losses of head on the several pipes calculated by equation (5) for a discharge of 1 000 000 galls. a day, or for $q = 1$.

TABLE No. 1.—Diameters, Heights, and Hydraulic Grades for the Steel Pipes, *A B*, *B C*, *C D*, and the Cast-Iron Pipe, *D E*, *E F*, *F G*.

Pipes.				Elevations above City Base.					
Material.	d.	Section.	l.	Point.	Height.	Point.	Height.	H.	h.
Steel.......	42"	*A B*	52 915	*A*	710.4	*B*	646.2	64.2	1.213
"	35"	*B C*	41 034	*B*	646.2	*C*	533.2	113.0	2.754
"	33"	*C D*	34 345	*C*	533.2	*D*	405.0	128.2	3.733
Cast iron..	32"	*D E*	21 460	*D*	401.8	*E*	—4.2	406.0	18.890
"	28"	*E F*	2 006	*E*	335.3	*F*	5.1	9.3	4.650
"	32"	*F G*	9 613	*F*	5.1	*G*	292.8	287.7	29.928

The city base is 6.18 ft. above low tide at the low-water stage of the Willamette River. The elevations at the upper ends, *A* and *D*, of the steel and cast-iron pipes are corrected by deducting the head lost in generating the velocity. The elevation of *D*, 405, at the end of the steel pipe is the height of the water above the weir, but for the upper end of the cast-iron pipe it is the surface of the water below the weir. At the ends of the pipes the elevations are estimated to the tops of the pipes or to the surface of the water.

On February 27th, 1896, with the elevations of the water surfaces at *A*, *D* and *G*, as given in Table No. 1, the discharge was 23 500 000 galls. through the riveted pipes, and 20 750 000 galls. through the cast-iron pipe.

The 42-in. pipe did not run full beyond a point *A'* at an elevation of 648.5 ft., and 1 950 ft. east of the junction *B* of the 42-in. and 35-in. pipes.

The 35-in. pipe was partially full at the upper end, and at a point *B'*, 1 205 ft. west of *B*, the elevation of the hydraulic grade was 633.1 ft., by piezometer measurement. The elevation of the water surface was 532.5 at the junction of the 35-in. and 33-in. pipes, beyond which the 33-in. pipe was only partially full. At a point *C'* on the 33-in. pipe, 163 ft. west of *C*, the elevation of the hydraulic grade was 527.1 ft. by piezometer measurement.

On the compound cast-iron pipe, the elevations in Table No. 2 are those of the piezometer grades, calculated by equation (6). For the steel pipes the coefficients are calculated from the hydraulic grades.

TABLE No. 2.—Diameters, Grades and Coefficients of the Steel Pipes, *A A'*, *B' C*, *C' D*, and of the Compound Cast-Iron Pipe, *D E*, *E F*, *F G*.

Pipes.				Elevations above City Base.							
Material.	d.	Length, l.		Point.	Height.	Point.	Height.	H.	h.	q.	c.
		Section.	1 000 ft.								
Steel....	42"	*A A'*	50.965	*A*	710.4	*A'*	648.5	61.9	1.215	23.5	115.9
"	42"	*A' B*	1.950	......	....	......	....	......	......	......	......
"	35"	*B B'*	1.205	......	....	......	....	......	......	......	......
"	35"	*B' C*	39.829	*B'*	633.1	*C*	532.5	100.6	2.526	23.5	126.8
"	33"	*C C'*	.169	......	....	......	....	......	......	......	......
"	33"	*C' D*	34.176	*C'*	527.1	*D*	405.0	122.1	3.572	23.5	123.2
Cast iron.	32"	*D E*	21.460	*D*	401.8	*E*	335.3	66.5	3.100	20.75	126.2
"	28"	*E F*	2.006	*E*	335.3	*F*	322.6	12.7	6.340	20.75	123.4
"	32"	*F G*	9.613	*F*	322.6	*G*	292.8	29.8	3.100	20.75	126.2

Assuming p equal to h, and the lengths and grades to be as given in the preceding tables, the values of c and q for clean straight pipes, according to Hamilton Smith, M. Am. Soc. C. E., and J. T. Fanning, M. Am. Soc. C. E., and for $n = 0.0115$ in the Kutter formula, would be as follows:

TABLE No. 3.

d.	h.	Smith.		Fanning.		Kutter.			Table No. 2.
		c.	q.	c.	q.	n.	c.	q.	c.
42"	1.213	137.0	27.75	129	26.73	.0115	130	26.38	116
35"	2.754	136.5	26.41	125	24.19	.0115	124	24.00	127
33"	3.733	136.0	26.45	124	24.11	.0115	124	24.11	123
32"	3.100	135.0	22.15	123.5	20.26	.0115	123	20.19	126
28"	6.240	134.0	22.52	121	20.33	.0115	121	20.33	123

With the coefficients corresponding to $n = 0.0115$, the values of p, and the discharge of the compound 42-in., 35-in. and 33-in. pipes, calculated by equation (6), would be as follows:

TABLE No. 4.

d.	c.	Length.			Head lost $o = l \times p$.	Elevations of Grade.				q.
		Section.	1 000 ft.	p.		Point.	Height.	Point.	Height.	
42"	130	A B	52.915	1.048	55.2	A	710.4	B	655.2	24.5
35"	124	B C	41.034	2.871	117.9	B	655.2	C	537.4	24.5
35"	124	C D	34.345	3.852	132.3	C	537.4	D	405.0	24.5
		Total head lost............			305.4	=	710.4 — 405.0			

The actual discharge, 23 500 000 galls., is 1 000 000 galls. more than was ordered, and 1 000 000 galls. less than would have been attained if the capacity of the 42-in. pipes had been proportional to that of the 35-in. or 33-in. pipes.

Of the three steel pipes the 33-in. was the straightest, and the coefficient should not have been 3% below that of the 35-in. pipe. The 42-in. pipe was over very rough ground, with many bends and summits, some of which rise very nearly to the line of the hydraulic grade, but the minimum radius of curvature was four times the diameter of the pipe, and there is no apparent reason for the reduc-

tion of the coefficient and discharge to 10% less than it would have been on the supposition that the conditions were the same as those of the other riveted pipes.

When the water was first turned on, in December, 1894, the height of the water surface at the head works was about 710.4 ft., and the discharge by the floating gauge at the end of the 33-in. pipe was 24 900 000 galls., but as it has since remained steadily at 23 500 000 galls. under like conditions, either the gauge must have been out of adjustment or air must have accumulated at some of the numerous summits.

The air valves which have been placed on all summits have been examined; men have been sent through the whole length of the pipe to see that there were no obstructions, and that the 42-in. gate below the trumpet-shaped mouth-piece at the head was fully open; and the screens have been raised to see that they did not diminish the flow, but, although some of the flatter summits may have escaped observation, nothing has as yet been discovered which accounts for the deficiency in the capacity of the pipe.

It will be seen by reference to Table No. 3 that, except for the 42-in. pipe, the coefficients are about the same for the cast-iron and steel pipes, and agree nearly with the coefficients of Mr. Fanning for clean pipes and those of the Kutter formula, for $n = 0.0115$.

A. L. Adams, M. Am. Soc. C. E., engineer of the water-works recently constructed in Astoria, Ore., states that the supply main there is compounded of a 16-in. steel riveted pipe and an 18-in. wood-stave pipe; that the coefficient for the former corresponds almost exactly with the value given by Mr. Fanning for clean, straight cast-iron pipes, and to the value $n = 0.0111$ in the Kutter formula, and is only 84½% of the coefficient for the 18-in. stave pipe.*

The riveted pipes on which the experiments of Mr. Smith were made were put together stove-pipe fashion, and the high coefficients deduced may be due in part to the lesser frictional resistance resulting from this method of construction, but the projecting edges of the laps on the inside of a pipe are smoothed and rounded by the asphalt coating, and the increase of friction resulting from constructing the pipes in rings with large and small sections does not appear to be important when the thickness does not exceed ¼ in.

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* See *Transactions*, Vol. xxxvi, p. 26.

The assumption on which the preceding calculations are based, that the piezometer grade p, which would be the grade of a line along the water surfaces in a series of open-topped tubes extending upward from the pipe, coincides with the hydraulic grade h of a straight line from the upper to the lower end of a pipe is true only when the inner surface opposes a frictional resistance which is uniform throughout the whole length of the pipe. In such cases the coincidence of the grade lines depends solely on the uniformity and not on the amount of the frictional resistance. The discharge depends on the amount of the friction, and is proportioned to coefficients of discharge determined experimentally and corresponding to the roughness n in the Kutter formula.

According to the principles of the Kutter formula the coefficient c is independent of the slope in the equation $v = c\sqrt{r h}$, when r is greater than 0.1 ft. and h is greater than 1 ft. in 1 000 ft.

According to experiments on the flow of water through pipes the variation of the coefficient is greater, but the difference may be due, in part at least, to the use of the term in a sense not warranted by the conditions of flow in open channels.

In the case of an open channel with a constant discharge and with irregular cross-sections or a variable roughness of the sides and bottom, the velocity and volume of the water vary in accordance with the slopes and the resistances to the flow in different sections of the channel, and an obstruction placed in one section does not diminish the discharge or appreciably affect the velocity or volume of the flow in other sections, except for a short distance above or below the obstruction. In the case of a full pipe there can be no difference in the velocity or sectional area of the water, and an obstruction to the flow at any one point is followed by a change in the pressure against the inner surface at all points, which would affect the piezometer grades along the whole length of the pipe, and has the same effect on the discharge as a change in the hydraulic grade.

To calculate the flow of water in open channels by hydraulic formulas the hydraulic grade h must be used, and for pipes the piezometer grade p, which may be less, but cannot be greater than h.

A pipe laid on the hydraulic grade line $A\ B$ would run full with a discharge q, given by equation (2), and a grade h, and only partially full with a less discharge q'. Should the pipe be laid under the hy-

draulic grade line, it would run full with the discharge q', but the grade would be reduced to p', calculated for the lesser discharge by equation (4).

Suppose two pipes with the same diameter and hydraulic grade, with discharges q and q' (the first calculated from the hydraulic grade), the reduction of the discharge from q to q' could be attributed to a greater roughness corresponding to a coefficient c', or to a change from the hydraulic grade h to the piezometer grade p', given by equation (4), and the values of c' and p' would be determined by the following equations, assuming the grades and coefficients to be independent quantities.

$$c' = c \times \frac{q'}{q} \text{ when } p' = h \ldots\ldots\ldots\ldots\ldots\ldots (a)$$

$$p' = h \times \left(\frac{q'}{q}\right)^2 \text{ when } c' = c \ldots\ldots\ldots\ldots\ldots\ldots (b)$$

The discharge would be the same in either case, but the pipe, if laid on the hydraulic grade, would run full with a roughness corre-

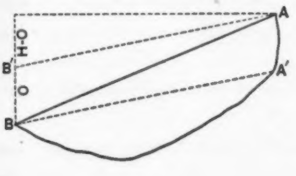

Fig. 2.

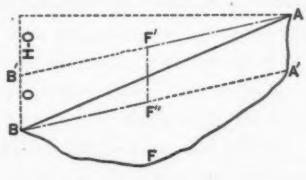

Fig. 3.

sponding to c' in equation (a), and partially full with the grade p' in equation (b), and a roughness corresponding to the coefficient c.

Should the discharge be decreased from q to q' through an open-topped pipe with a hydraulic grade line $A\,B$ (Fig. 2), the water would fall to a hydraulic grade line $A'\,B$, and the grade would be given by equation (4).

Suppose H to be the vertical fall from A to B, O the vertical fall from A to A', and l and k to be the lengths of the pipes $A\,B$ and $A\,A'$, the grade $h' = p'$ would be given by either one of the following equations or by equation (4):

$$p' = \frac{H - O}{l - k} = h \times \left(\frac{q'}{q}\right)^2 \ldots\ldots\ldots\ldots\ldots\ldots (c)$$

Suppose k to be small in comparison with l, the equation would be:

$$p' = \frac{H - O}{l} = h - o = h \times \left(\frac{q'}{q}\right)^2 \ldots\ldots\ldots (d)$$

Should the supply be taken from a reservoir with a surface level fixed at A (Fig. 3), the hydraulic grade could not change, but the piezometer grade would be reduced from h to $h \times \left(\frac{q'}{q}\right)^2$.

Should the loss of head O be due to the partial closing of a stop valve F, causing a vertical fall in the piezometer line below F, the grades would be on the parallel lines $A' B$ or $A B'$, should the valve be placed at A or B, and on the lines $A F'$, $F'' B$, should it be placed between A and B. In the latter case the grade lines would be on different sides of $A B$, but in each case O would be the vertical distance between the parallel grade lines; the grade p would be given by equation (d), and the pipe, if laid on the grade h, would be only partially full below the obstruction.

In these examples the whole loss of head has been supposed to take effect at one point, F, but should there be obstructions at several points, O would still represent the sum of the losses. The piezometer grades would descend in parallel lines between the obstructions like the steps of a stairway, and although there might be a considerable difference in the grades, the lines might continue close together, and would tend to coincide should the losses of head be equal and at uniform distances apart.

To the assumption that the piezometer grade is on the straight line between the heights of two points in the piezometer grade lines may be ascribed the variation in the coefficients deduced from piezometer measurements, so called.

For a series of compound pipes the loss of head for each one is determined by equation (5), and the discharge must be such that the sum of the losses in the several pipes must be equal to the total loss of head or vertical fall H from the upper to the lower end of the compound pipe, subject to the condition that the pipe must not rise at any point above the piezometer grade line. Examples are shown in Table No. 4 in the case of the 42-in., 35-in. and 33-in. pipes, and in Table No. 2 in the case of the compound 32-in. and 28-in. cast-iron pipe.

In a compound pipe the resistance to the flow of water in the several parts varies with the diameters, the degrees of roughness, and the local obstructions, and the piezometer grades fall in parallel lines on sections of uniform resistance, and vertically in the cases of local obstruc-

tions, like the surface of the water of an open channel, but with the important distinction that while in one case the grades depend on the actual slopes in the different sections, in the other they are due to variations in the pressure from obstructions on the inner surface, the effect of each one of which is felt throughout the whole length of the pipe.

It follows that when the two end sections of a pipe present equal and uniform resistances to the flow, the piezometer grade lines must lie on different sides of the hydraulic grade line, *A B* (Fig. 4), and must cross it at one or more points, and that the coefficients calculated on the assumption of a straight grade line do not indicate the roughness of the inner surface.

The hydraulic grade line *A A′ B* (Fig. 5), for instance, of the 42-in. riveted pipe falls at the rate of 1.213 ft. per 1 000 ft. to a summit *A′* west of the Sandy River, and the pipe is extended thence, along the hydraulic grade line, 2 000 ft. to a point *B*, at the end of the pipe.

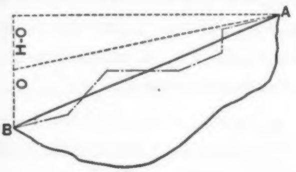

FIG. 4.

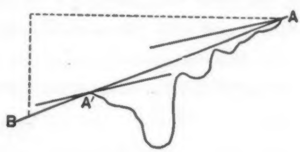

FIG. 5.

With a coefficient $c = 130$ (see Table No. 3), corresponding to the roughness of the 35-in. and 33-in. pipes, and to $n = 0.0115$, the discharge would have been 26 380 000 galls. in 24 hours, but it was only 23 500 000 galls. If the deficiency is due to the uniform roughness of the inner surface, the pipe would run full on the hydraulic grade line *A′ B*, and the coefficient $c' = 130 \times \frac{23.50}{26.38} = 116$ would indicate a roughness equal to 0.0125. But the fact that the pipe does not run full from *A′* to *B* shows that the roughness is less than 0.0125 and that the grade is less than the hydraulic grade, and the reduction of the discharge may be ascribed to a reduction of the grade from $h = 1.213$ to $p' = h\,x \left(\frac{23.50}{26.38}\right)^2 = 0.963$, on account of bends, accumulations of air at summits, or causes not connected with the degree of roughness or the coefficient of discharge.

A difference of 3 ins. in 1 000 ft. could not be detected readily, but measurements by pressure gauges show conclusively that the piezometer is above the hydraulic grade line at A and below it at A', and that the two lines cross at one or more intermediate points.

The difference of the grades multiplied into the length of the pipe, $o = (1.213 - 0.963) \times 52.9 = 13.225$, is the vertical distance between the parallel grade lines through A and A' and represents the total loss of head from irregular obstructions; but the difference in the elevations of the two grade lines, as measured by pressure gauges, does not at any point exceed 3 ft. Assuming, then, that there must always be a diminution of the grade from irregular obstructions, it will follow that the coefficients calculated by using the hydraulic grade in equation (3) are always too small, especially when o is small in comparison with h, and this may perhaps account for the great variation where the grades are light.

In Table No. 5 coefficients calculated from hydraulic grades are given from Mr. Fanning's tables and from the measurements of the 48-in. cast-iron pipes of the Boston Water-Works*; also the value of o in the equation, $p = h - o$, which would give a uniform value to the coefficients. The grades are in feet per thousand.

TABLE No. 5.

Authority.	Diameter, inches.	Grade. h.	c.	Grade. $p = h - o$.	c.	Pipes.
Fanning........	6	1.409	98.3	$h - .020$	105	Clean straight.
"	6	2.976	101.7	$h - .032$	105	"
"	6	3.827	102.7	$h - .047$	105	"
FitzGerald......	48	0.0115	116.5	$h - .003$	144	Clean.
"	48	0.0689	134.1	$h - .009$	144	"
"	48	0.3234	137.5	$h - .030$	144	"
"	48	0.7182	138.9	$h - .050$	144	"
"	48	1.2414	141.1	$h - .050$	144	"
"	48	1.8283	143.6	$h - .057$	144	"
"	48	0.0159	101.2	$h - .002$	110	Tuberculated.
"	48	0.0202	88.0	$h - .007$	110	"
"	48	0.5149	108.7	$h - .002$	110	"
"	48	1.1299	109.4	$h - .012$	110	"
"	48	2.6368	108.9	$h - .054$	110	"
Smith..........	42	1.213	116.0	$h - .250$	130	Steel riveted.

The coefficient 144 in the table is the same as that determined by Mr. FitzGerald for the 48-in. pipes with tubercles removed and a velocity of 6.195 ft. per second, but for the tuberculated pipes no definite conclusion can be drawn where the grades are very small, the

* See *Transactions*, Vol. xxxv, pp. 266, 267.

coefficients being 114.8 in one case, for a slope of 0.0287 per 1 000, and 88 in another instance for a slope of 0.0211. This difference may be ascribed to the liability to error in measuring very small slopes, but for greater grades there does not seem to be so great a variation in the coefficients as with the clean pipes, which tends to support the principle of the Kutter formula that, except for very small slopes, the coefficients are constant for the same diameter of pipe, which would be more apparent should the slopes and coefficients be used as co-ordinates in diagrams, and the velocities be left out of consideration, or treated as functions of the grades. The effect of a small difference in the grades on the discharge will show the necessity of accurate measurements where the grades are light and the pipes not more than 1 000 or 2 000 ft. in length. For the 42-in. pipe, for instance, a difference of 3 ins. in 1 000 ft. makes a difference of nearly 3 000 000 galls. in 24 hours.

In regard to the effect of long use on the tuberculation of the inner surfaces of pipes, the following information is presented from experience with the pipe system of the city of Portland. The supply was first taken from small creeks, to which was added 28 years ago a plant for pumping from the Willamette River, which carries a large amount of mud and sand during floods. The use of this plant was afterward discontinued and a new pumping station erected 12 years ago, with a 4-mile force main of 30-in. riveted pipes of No. 6 wrought iron. The pump main laid 28 years ago was 18 ins. in diameter and of No. 6 wrought iron. It was laid on trestles across ground overflowed at high water, and was not protected from the weather. The coating was displaced on some portions of the pipe, but otherwise it appears perfectly clean and sound, and portions are now being used in the distribution system of the city under a pressure of 90 lbs. to the square inch. A portion of the 30-in. riveted pump main was taken up, and the coating was found to be intact and the pipe perfectly clean and sound. The cast-iron pipes from 6 to 24 ins. in diameter are free from tuberculation, so far as can be ascertained. The only exception is a 4-in. pipe which has been in use for 15 years and is rusted and rough on the inside, but it does not appear that this pipe was coated.

The Bull Run water is probably of the same nature as that of the Willamette River, except that it is always clear, and it is not probable that it will have a different effect on the pipes.

CORRESPONDENCE.

Mr. Adams. ARTHUR L. ADAMS, M. Am. Soc. C. E.—In determining the coefficients for the 28-in. and 32-in. cast-iron pipes, the author seems to have treated the two as being similar in character, and, dealing with them as a compound pipe, has determined by calculation the relative losses of head in the two sizes. This treatment may have led to an erroneous conclusion regarding the carrying capacity of the 32-in. cast-iron pipe as compared with the steel riveted pipe. The 28-in. pipe is all of the flexible ball and socket joint type, a joint of this character occurring every 15 ft. 10 ins.* It is laid in the direction of flow, so that besides the necessary enlargement of section, the water impinges more or less against the end of the ball at every joint. Again, in laying a line of this character, it would seem to be unavoidable that there should be many angles, both vertical and horizontal. These do not seem to have been taken into account in tabulating the curvature. In view of these facts, especially the probable large resistance to flow afforded by the flexible joints, it would seem that had the loss in the 28-in. pipe been determined independently of that in the 32-in., in all probability the coefficient for the 32-in. pipe would have been found to be considerably greater than that stated. Such a result would accord more nearly with what might reasonably be expected, and would afford an explanation for what otherwise seems almost incredible in the paper as presented, that the cast-iron hub and spigot pipe possesses practically no advantage over the steel riveted pipe in discharging capacity.

Mr. Le Conte. L. J. LE CONTE, M. Am. Soc. C. E.—The lack of capacity in the upper section of the 42-in. pipe line, from the inlet down to *B*, may be naturally ascribed to two causes:

First.—The summits of the pipe line near the hydraulic grade line and the 2 000 ft. of pipe east of *B*, which is on the grade line, will always give rise to extra trouble, with constant accumulation of air near the summits. The fact that the capacity was 24 900 000 galls. per day, but soon after settled down to 23 500 000 galls. would seem to show a loss in capacity of 1 400 000 galls. or 5.6%, due to air obstructions alone. In many instances to the writer's knowledge these air cushions are seldom or never located right at the top of the summits, but at a certain distance from it toward the outlet, depending upon the velocity of the flow and the slope of the down-stream leg of the syphon. If the latter is a flat slope, the air cushion may be found some distance from the summit. The location of these troublesome air cushions is a special study in every pipe line and their position cannot always be

* See *Transactions*, Vol. xxxiii, p. 258.

predicted with certainty, for the obvious reason that their location is liable to change, more or less, with every change in the velocity of the water column. The friction of the moving water against the bottoms of the air cushions causes them to take apparently abnormal positions along the pipe line. Consequently the selection of the best site to place a given air valve is more or less a tentative problem. Where the velocity of the water column is considerable, say 4 ft. per second, it sometimes happens that the first location of the air valve is not the proper one. These remarks apply with equal force when an engineer is called upon to fix the proper sites for his blow-off valves near the bottom of his syphons, to free his pipe line from sandy deposits. Mr. Le Conte.

Second.—The author states that in the middle portion of the upper syphon, *A B*, there is half a mile of pipe made of ⅜-in. steel plates, No. 00 B. W. G. This heavy section is the controlling feature in fixing the value for the coefficient of roughness, *n*, in the Kutter formula. Recent observations by Emil Kuichling, M. Am. Soc. C. E., on the Rochester pipe lines show a marked variation in the value of the velocity coefficient, *c*, on the same pipe line where different sections were made of different thicknesses of metal. Experience in California also shows that on any given riveted pipe line the velocity coefficient, *c*, always diminishes with the thickness of the iron plates, which is perfectly natural. Hence it necessarily follows that in case of deep syphons the hydraulic grade is not a right line from the inlet to the outlet, but a broken line, or, more exactly speaking, a flattened reverse curve, having the steeper grade in the middle and flatter grades both above and below.

The author has stated that the 42-in. pipe, where built on the hydraulic grade, lacks about 4.5 ins. of flowing full. It is made of steel plates 0.203 in. thick. The actual discharge of this partly full section is found to be 23 500 000 galls. per day, and seems to establish a local value for *c* of 125 for this thickness of iron plate, which is reasonable. This being the case, it does not seem unreasonable to suppose that the heavier iron on both legs of the syphon, together with the half mile of ⅜-in. iron pipe in the lower portion of the syphon, with sharp bends, would fully account for the balance of the loss in capacity, 4.5%, and thus make the effective coefficient of velocity, *c*, for the entire section, *A B*, approach somewhere near 116, which observation shows is the case.

It may be well to mention an extreme case in practice. The old Virginia City pipe line in Nevada, built in 1872, is a 12-in. wrought-iron riveted pipe in the form of a prodigious syphon, having a maximum pressure midway of 764 lbs. per square inch, due to a head of 1 720 ft. of water. The middle portion of the syphon called for plate iron $\frac{11}{32}$ in. thick and correspondingly heavy rivets. The interior

Mr. Le Conte. surface of the pipe was necessarily very rough. When the water was turned on, observations showed a low velocity coefficient, viz., $v = 78 \times \sqrt{r\,s}$.

Mr. Smith. ISAAC W. SMITH, M. Am. Soc. C. E.—Mr. Adams thinks that it is "almost incredible" that the cast-iron hub and spigot joint pipe should possess "practically no advantage over the steel riveted pipe in discharging capacity," and that if, for reasons stated, a lower coefficient had been assumed for the 28-in. ball and socket joint pipe, "the coefficient for the 32-in. pipe would have been found to be considerably greater than that stated." The 32-in. pipe, 31 073 ft. in length, was compounded with 2 006 ft. of a 28-in. ball and socket joint pipe under the Willamette River.

The 28-in. pipe was laid in a trench dredged to grade, on which there were two horizontal bends of 11 ft. radius, each of 21°, so that the curvature was not so great as on the 32-in. pipe.* The actual loss of head on the 28-in. pipe, measured as accurately as was possible by pressure gauges, was 11.2 ft., and the loss of head calculated in Table No. 2, for a coefficient of 123.4, was 12.7 ft., giving for the 32-in. pipe a coefficient of 126.2. As the lengths of the compounded 28-in. and 32-in. pipes were 2 000 and 31 000 ft., a reduction of 20% in the coefficient of one would not have resulted in an increase of more than 3% in the coefficient of the other.

Mr. Adams has stated† that he found the coefficient of a 16-in. steel riveted pipe on the Astoria Water-Works to correspond almost exactly with the value given by J. T. Fanning, M. Am. Soc. C. E., for clean, straight, cast-iron pipes of the same diameter. As the measurements have been accurately made, there is, therefore, nothing to discredit the conclusion that the coefficients are the same for the 33-in. steel riveted and the 32-in. cast-iron pipes.

The 33-in. and 35-in. pipes are all of No. 6 B. W. G. plates, 0.203 in. in thickness. On the 42-in. pipe there are 33 516 ft. of No. 6 (0.203 in.); 16 411 ft. of No. 4 (0.238 in.), and 2 703 ft. of ⅜-in. thickness. The lower section of the 42-in. pipe, 2 000 ft. in length, is of No. 6 steel and laid on the hydraulic grade of 1.213 to 1 000. On this section the pipe does not run full, and the calculated coefficient of discharge is about 130, which corresponds nearly with the coefficients of the 35-in. and 33-in. pipes, taking the diameters into consideration. On the remainder of the pipe the coefficient calculated from the discharge is 116, which is about 10% less than 130. Of this, 5½% is ascribed by Mr. Le Conte to air cushions at or near the summits, and 4½% to additional friction from the increase in the size of the rivet heads in the No. 4 and ⅜-in. plates.

* See table of bends, page 201.

† See *Transactions*, Vol. xxxvi, p. 26.

Mr. Smith.

In relation to the discharge of 24 900 000 galls., by weir measurement, for a few hours when the water was first turned on in December, 1894, the author is of the opinion that it was due to an erroneous adjustment of the gauge, because the water has since that date been repeatedly turned off and on, and the discharge has always been about 23 500 000 galls. During the past eighteen months a careful examination has been made to locate the possible air cushions near the summits. Additional air-cocks have been placed wherever there seemed to be a probability of the accumulation of air, and men have been twice sent through the whole length of the pipe, but in no instance has there been any evidence of deposits in the lower portions of the pipe or accumulations of air at or near the summits.

For these reasons, and because the many summits on the 35-in. and 33-in. pipes have not appreciably affected the flow, the author is of the opinion that the low coefficient of the 42-in. pipe, as compared with that of the 35-in. and 33-in. pipes, is not due to the accumulation of air at summits.

Between the sizes of the rivet heads for the No. 6 and No. 4 plates on the 42-in. pipe, there is no appreciable difference, and to reduce the coefficient from 130 to 116 on the 48 260 ft. of No. 6 and No. 4 pipes, would require a reduction of the coefficient for the 2 700 ft. of $\frac{3}{8}$-in. pipe to 20.4. For this reason, and because the rivet heads on the No. 6, 35-in. and 33-in. pipes do not materially reduce the discharge, the author ascribes the deficiency in the relative capacity of discharge of the 42-in. pipe, not so much to the larger size of the rivet heads on 27% of the length of the pipe, as to a misconception of the meaning and significance of the grade s in the hydraulic formula $v = c\sqrt{rs}$, and to the erroneous assumption that the pipe may be laid up to the line of the hydraulic grade without reducing the discharge.

Suppose, for instance, $A\ B$ (Fig. 2) to be the hydraulic grade (1.213 to 1 000) of a 42-in. pipe 50 965 ft. in length and with a roughness of the interior surface corresponding to a coefficient of discharge equal to 130; then, should there be no other resistance to the flow, the discharge in 24 hours would be 26 380 000 galls., as per Table No. 3, provided the pipe did not rise at any point above the line $A\ B$. Should the discharge be only 23 500 000 galls. the grade p, see (4), page 202, would be 0.963 per 1 000, and the loss of head due to other causes than the uniform roughness of the pipe would be 13.22 ft.

Should the water surface fall vertically a distance $O = 13.22$ from A to A' (Fig. 2) on account of an insufficient flow into the upper end of the pipe, the grade p and the hydraulic grade h would be on the line $A'\ B$ and equal to 0.963, and the discharge q, calculated by (2), page 202, would be 23 500 000 galls. a day, provided that no portion of the pipe should be laid above the line $A'\ B$ of the hydraulic and piezometer grade.

Mr. Smith. Should the flow be reduced to 23 500 000 galls. by bends, gates or other local obstructions, the upper level of the water in the pipe remaining constant at A, the hydraulic grade h would remain constant at 1.213, but the grade p, calculated by (4), page 202, would be 0.963, and the piezometer grades would vary according to the nature and locations of the local obstructions.

Should the whole reduction of the discharge be due to the partial closing of a gate at the lower end of the pipe, $A\ B'$, parallel to $A'\ B$, and above the line $A\ B$ of the hydraulic grade, would be the piezometer grade. Should the gate be placed at F (Fig. 3) between A and B, $A\ F'$ and $F''\ B$, parallel and on different sides of $A\ B$, would be the lines of the piezometer grades.

Should the reduction of discharge be due to irregular obstructions at different points between A and B, the line of the piezometer grades would be broken, and although it might coincide nearly with that of the hydraulic line, there might be a considerable difference in the grades, and when determined on the assumption that it is on a straight line, the piezometer grade would not be the same as the true or hydraulic grade.

It is evident that the pipe should not be laid up to the line $A\ B$ of the hydraulic grade, when, as in Fig. 3, it is above the line $F''\ B$ of the piezometer grade, and it is questionable whether it should be laid up to the line $A\ B'$ (Fig. 2) or $A\ F'$ (Fig. 3) of the piezometer grade when it is above the line $A\ B$, or whether the pipe should be laid at any point above the line $A'\ B$ of the grade p, calculated from the discharge by (4), page 202.

On the 42-in. pipe the line of the hydraulic grade coincided nearly with the line of the piezometer grades determined by pressure gauges, and the pipe does not rise at any point above either line, but in the opinion of the author the deficiency in the discharge is due to the elevation of the pipe at three points within 2 miles of the head works to within from 4 to 7 ft. of the hydraulic grade line.

The coefficient c and the slope s in the hydraulic formula $v = c \times \sqrt{r\ s}$, have a definite meaning in application to an open channel, but not in application to a syphon pipe, and to this may be ascribed in part the variation in experimental results, but by making liberal allowances for the loss of head from irregular and local obstructions and giving a wide margin to the line of the hydraulic grade, the formula will be found to be "equalled by few and excelled by none."